TUNABLE FILTER WITH A WIDE FREE SPECTRAL RANGE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a tunable filter with wide free spectral range, in particular to a micro-electromechanical system (MEMS) tunable filter using a resonance cavity with improved optical performance and stability, simplified construction and low costs.

2. Description of Related Arts

Dense wavelength division multiplexing (DWDM) is often used to increase the capacity of a fiber optic communication, but these DWDMs need optical filters to select signals, with specific wavelengths, passing through the optic fiber.

The conventional method of assembling the optical filter is by direct coupling of fiber cables without a resonance cavity, which has the advantage of small size, but after the addition of a non-MEMS external actuator, the size advantage is cancelled out.

Another method is to use fiber coupling with resonance cavity, as shown in Fig. 5, by using two collimators (71, 72) to create a resonance cavity (70), but the reflection loss through an optical filter without proper tilt angle cannot meet the requirements for optical signal transmission.

For those fiber couplings without a resonance cavity, the optical path can be interfered by various external factors such as changes in temperature and vibration, causing instability in optical transmission, and a drastic change in insertion loss. In Fig. 6, the two opposing lenses (73) (74) of the filter basing on direct coupling with a resonance cavity can be as either plane to plane or plane to concave. The relation between the insertion loss and the tilt angle is demonstrated in Fig. 7. If the two opposing lenses (73) (74) are plane-plane, the insertion loss is subjected to high sensitivity as the tilt angle α increases. If one of the opposing lenses is concave, then the sensitivity to insertion loss decreases notably, as compared with the plane-plane configuration mentioned above.

Furthermore, the assembling cost for this type of filter including three ferrules and two piezoelectric actuators is quite high. Even if the MEMS fabrication technique is employed for the resonance cavity using two Bragg reflectors (DBR), these two Bragg reflectors still have to be joined by chip bonding with related facilities. Because of the

addition of the piezoelectric actuator, the overall size of the filter cannot be reduced and the costs cannot be lowered.

For MEMS tunable filters, the resonance cavity is formed between two distributed Bragg reflectors (DBR). The basic structure of an MEMS tunable filter using an electrostatic actuator is shown in Fig. 8, including an anti-reflection coating (AR) (81) formed over a substrate (80), a first mirror (82), a lower electrode (83), a dielectric layer (84), an upper electrode (85) and a second mirror (86) consecutively formed over the first mirror (82); and then another substrate (87) formed over the second mirror (86) to hold the second mirror (86) in a fixed position. The second mirror (86) has a concave lens surface that is opposed to the first mirror (82). A resonance cavity is formed in the space between the two mirrors (82, 86) and has an axial length of 33um. The substrate (87) has an aperture (870) on the opposite side of the concave lens.

For modulating the wavelength of the signals passing through the optic fiber, a control voltage is applied through the upper and lower electrodes (83, 85) on the first and second mirrors (82, 86), whereby the second mirror (86) is drawn towards the first mirror (82) to close the gap between the two mirrors (82, 86).

An MEMS filter using a heat actuator is shown in Fig. 9. The basic structure includes an anti-reflection coating (91) formed on the bottom surface of a substrate (90), a first mirror (92) formed over the top of the substrate (90), and a passivation layer (93) and a second mirror (94) consecutively formed over the first mirror (92), and finally a substrate (95) to hold the second mirror (94) in a fixed position. The second mirror (94) has a concave lens as opposed to the plane lens of the first mirror (92). The two mirrors are separated by a passivation layer (93) thus creating a resonance cavity in between the mirrors. The axial length of the resonance cavity is about 40mm, and the substrate (95) has an aperture (950) opposing the concave lens.

The above mentioned MEMS filter having the resonance cavity is able to produce better optical performance and stability, but still has the following problems:

High production costs: since the two Bragg reflectors have to be joined together by the chip bonding technique, the production costs are high; and

Complicated fabrication: the resonance cavity poses a challenge for the fabrication process: the length of the resonance cavity has to be 40um for wide frequency operating range (FSR=50nm), but for applications requiring FSR of 400nm, such as image

spectroscopy and tunable color filters, the required length of the resonance cavity has to be 0.8um, thus the requirement for resonance cavity calls for a sophisticated fabrication process to produce the MEMS filters.

The conventional MEMS tunable filter having a resonance cavity was able to produce good optical performance and stability, but the production costs were high and the length of the resonance cavity was not easily adjustable to suit different wavelength requirements.

SUMMARY OF THE INVENTION

The primary object of the present invention is to provide an MEMS tunable filter with simplified construction of a resonance cavity, but which is able to produce high optical performance and stability with low costs.

The instrumentalities of the present invention to produce the above MEMS tunable filter include:

a first collimator;

a second collimator opposed to the first collimator; and

a reflector being interposed between the first and the second collimators with a high reflectivity lens, whereby a resonance cavity is defined in the space between the high reflectivity lens and the second collimator.

The high reflectivity lens on the second collimator can be an MEMS lens.

The second collimator having a high reflectivity lens can be adjusted to accomplish the axial length adjustment for the resonance cavity. Therefore, the wavelength of the light beams passing through the filter can be modulated by the filter.

The present construction does not require chip bonding or complicated fabrication processing, thereby the production costs can be reduced considerably as compared with the conventional techniques.

If the tunable filter is a heat-actuated type, the reflector is formed on a substrate by a standard DBR process with a multi-layer membrane on the surface of the substrate. The high reflectivity lens with a proper curvature is formed over an aperture defined on the substrate.

If the tunable filter is a an electrostatic-actuated type, the high reflectivity lens is formed on a substrate by a standard DBR process with a multi-layer membrane. The high

reflectivity lens has a curved surface over the aperture on the substrate. Furthermore, the reflector has a dielectric layer and an electrode layer formed on top the substrate wherein both the dielectric layer and electrode layer have an opening corresponding to the aperture on the substrate.

The features and structure of the present invention will be more clearly understood when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is the basic architecture of the present invention;

Fig. 2 is one preferred embodiment of the invention;

Fig. 3 is another embodiment of the invention;

Fig. 4 is the butterfly housing for assembling the optical device;

Fig. 5 is a traditional MEMS tunable filter having a resonance cavity;

Fig. 6 is a traditional MEMS tunable filter without a resonance cavity;

Fig. 7 is a diagram demonstrating the effect of resonance cavity on the insertion loss;

Fig. 8 is a cross-sectional view of the traditional MEMS tunable filter using an electrostatic actuator; and

Fig. 9 is a cross-sectional view of the traditional MEMS tunable filter using a heat actuator.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention provides an MEMS filter with the basic structure as shown in Fig. 1, comprising:

a first collimator (10);

a second collimator (20) opposed to the first collimator (10) and kept apart with an appropriate distance;

a reflector (30), such as a Bragg reflector, interposed between the first and the second collimator (10, 20), the reflector (30) having a multi-layer polymer film over an aperture (301) on a substrate (300).

The reflector (30) has a high reflectivity lens surface (31) with a curvature. The first collimator (10) has a lens surface with an anti-reflection coating (11), and the second

collimator (20) has a lens surface with a reflective layer (21). A Fabry-Perot resonance cavity (32) is defined in the space between the second collimator (20) and the reflector (30).

The reflective layer (21) of the second collimator (20) has a high reflectivity coating of Ta_2O_5 or SiO_2.

The operating principles of the present invention are to be described below. When the first collimator (10) receives a light beam, the beam passes through the concave lens surface (31) of the reflector (30) to reach the resonance cavity (32) formed between the concave lens surface (31) and the second collimator (20), and after producing resonance the light exits through the second collimator (20).

Since the reflector (30) having the concave lens surface (31) can be adjusted to change the distance between the reflector (30) and the second collimator (20), thereby the wavelength of the light passing through the resonance cavity (32) can be modulated. Therefore, the MEMS filter is able to suit applications requiring different wavelengths.

According to the present invention, the above mentioned resonance cavity is created with only one reflector (30), and the formation of the MEMS filter requires no chip bonding, thus the production costs can be effectively reduced.

Furthermore, the resonance cavity (32) is determined by the distance between the concave lens (31) of the reflector (30) and the second collimator (20), therefore by changing the position of the second collimator (20) the axial length of the resonance cavity can be easily adjusted.

The present design can avoid the problem of using dual Bragg reflectors and so eliminates the complicated fabrication process, but the MEMS filter is able to meet the high frequency operating range (FSR=400nm) to suit a wide range of optic fiber applications.

In addition, the reflection loss (BR) of the filter is largely compensated by the first and second collimators (10, 20).

Since the MEMS actuator is embedded in the filter, the overall size of the filter can be reduced considerably.

A variable wavelength filter of a heat-actuated type is shown in Fig.2. The reflector (30) is coated with a multi-layer film. The concave lens surface (31) of the reflector (30)

possesses a curvature, and is formed over the aperture (301) of the substrate (300). The multi-layer membrane is formed by alternate layers of GaAs and AlAs.

When heat is applied on the reflector (30), the displacement of the reflector (30) changes the distance between the concave lens surface (31) of the reflector (30) and the second collimator (20).

A variable wavelength MEMS filter of an electrostatic-actuated type is shown in Fig. 3. The reflector (30) also comprises a lens surface (31) formed by a multi-layer film extending over the aperture (301) on the substrate (300). The concave lens (31) of the reflector (30) corresponds to the position of the aperture (301) of the substrate (300). The reflector (30) further has a dielectric layer (40) and an electrode layer (50) formed over the surface creating openings (41, 51) over the aperture (301) on the substrate (300) and the concave lens surface (31).

When a control voltage is applied on the electrode layer (50) and the reflector (30), the concave lens (31) can be close to or away from the electrode (50), thereby the distance between the reflector and the second collimator (20) is changed, and the wavelength of the light beam passing through can be modulated.

The reflector (30) can be embedded in an MEMS chip, as shown in Fig. 4. The MEMS chip is placed at the center of a butterfly housing (60) in a chamber (61), with alignment cladding (62) on two ends of the housing (60), such that the space inside the cladding (62) is connected to the chamber (61). Each cladding (62) has several notches (620) on the external wall. The first and second collimator (10) and (20) are inserted into the two claddings (62) on both ends of the butterfly housing (60) having the lenses facing inward and opposing each other. The first and second collimator (10, 20) are aligned and thereafter fixed by electroplating through the notch (620) of the cladding (62).

The MEMS chip (63) is installed in the chamber (61) by anodic bonding, in between the first and second collimator (10, 20), and then the chamber (61) is hermetically sealed off.

The present invention employs a pair of collimators and a high reflectivity Bragg reflector (DBR) to create a Fabry-Perot resonance cavity, and an electrostatic or heat actuator is used to form an MEMS tunable filter. When compared with the conventional tunable filter using two Bragg reflectors, the production costs in the present design can be

effectively reduced and the fabrication process simplified. The MEMS tunable filter is able to provide better performance and stability and is small in size.

The foregoing description of the preferred embodiments of the present invention is intended to be illustrative only and, under no circumstances, should the scope of the present invention be so restricted.